

**VNIR AND TIR SPECTRA OF FINE-GRAINED MINERALS UNDER AMBIENT AND SIMULATED ASTEROID ENVIRONMENT CONDITIONS WITH APPLICATIONS TO OSIRIS-REX.** L. B. Breitenfeld<sup>1</sup>, A. Kling<sup>1</sup>, G. Kim<sup>1</sup>, A. D. Rogers<sup>1</sup>, T. D. Glotch<sup>1</sup>, V. E. Hamilton<sup>2</sup>, P. R. Christensen<sup>3</sup>, D. S. Lauretta<sup>4</sup>, and the OSIRIS-REx Team, <sup>1</sup>Dept. of Geosciences, Stony Brook University, Stony Brook, NY, [laura.breitenfeld@stonybrook.edu](mailto:laura.breitenfeld@stonybrook.edu), <sup>2</sup>Dept. of Space Science, Southwest Research Institute, Boulder, CO, <sup>3</sup>School of Earth and Space Exploration, Arizona State University, Tempe, AZ, <sup>4</sup>Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ.

**Introduction:** Bennu is a B-type asteroid [1, 2] with spectral properties similar to CI or CM chondrites [3, 4]. B-type asteroids exhibit blue slopes in the visible and near-infrared (VNIR), with weak or absent spectral features [5]. Yet, a ground-based spectrum of Bennu displays a red, rather than blue, spectral slope in the VNIR [4]. Though telescopic VNIR spectra of Bennu display a range of spectral slopes, all are nearly featureless at the noise levels of the detectors and show that Bennu exhibits a very low visible geometric albedo of  $0.04 \pm 0.01$  at 550 nm [2]. Here, we use 13 well-characterized synthetic and naturally occurring minerals to develop fine-grained, albedo-constrained VNIR and thermal infrared (TIR) spectral libraries applicable to partial least squares (PLS) analysis of the OVIRS [6] and OTES data sets from OSIRIS-REx. PLS has proved effective as a tool for evaluating compositional abundances using several types of spectroscopy [7-10]. Applying PLS to OSIRIS-REx data is not part of the automated SAWG analysis and therefore this work will be a unique investigation.

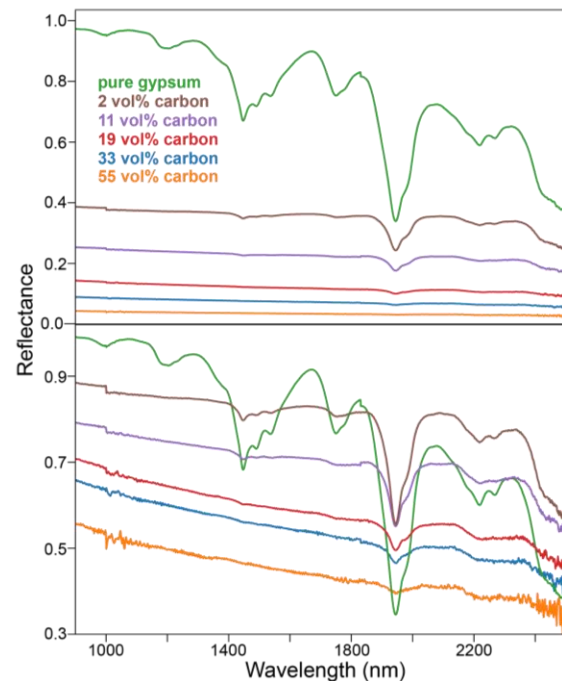
**Sample Preparation:** The 13 mineral species utilized here are commonly present within CI and CM chondrites [11-13]. These minerals include olivine (Fo40, Fo80, Fo100), calcite, dolomite, ferrihydrite, magnetite, pyrrhotite, gypsum, antigorite, saponite, enstatite, and cronstedtite. Suitable samples were obtained from several museum collections and dealers. Additionally, the enstatite (62-65% clino and 33-37% proto) and three olivine (Fo40, Fo80, and Fo100) samples were synthesized by Donald Lindsley and Nicholas DiFrancesco in Stony Brook University's Experimental Petrology Laboratory. Natural samples were hand-picked for purity and in some cases were acid-washed or magnetically separated.

After hand crushing or milling each sample, grain size distributions were evaluated using a laser diffractometer (Malvern Mastersizer 2000). Additional crushing was conducted until the majority of each grain size profile was less than 10 microns to produce fine grain samples necessary for this work.

A set of gypsum mixtures containing different proportions (0, 2, 11, 19, 33, and 55 volume%) of lamp black carbon powder were made to evaluate albedo changes with darkening and detectability of spectral features. Additionally, to account for the low albedo of Bennu, all 13 minerals were darkened using 19 volume% (1 weight%) carbon powder.

**Instrumentation:** TIR spectra were acquired for all samples under both ambient and simulated asteroid environment (SAE). To acquire spectra in SAE conditions, the Planetary and Asteroid Regolith Spectroscopy Environmental Chamber (PARSEC), a custom-built planetary environmental spectroscopy chamber at Stony Brook University, was utilized. PARSEC is coupled to a Nicolet 6700 FTIR spectrometer for TIR emission measurements.

Before ambient TIR measurements, the chamber was pumped down to  $10^{-2}$  mbar and then back-filled with  $N_2$ . For both SAE and ambient conditions, black-body measurements were acquired at 70 and 100° C while samples were heated to 80° C. The chamber was pumped down to  $\sim 10^{-5}$  mbar over several hours for SAE measurements and a liquid nitrogen-filled dewar cooled the chamber to  $< -120^\circ$  C. VNIR spectra were also collected on the same samples in ambient conditions using an ASD Fieldspec3 Max spectrometer.



**Figure 1.** Raw (top) and normalized (bottom) VNIR spectra of gypsum mixtures with 0, 2, 11, 19, 33 and 55 volume% carbon.

**Results:** VNIR spectra of the darkened gypsum mixtures are shown in **Figure 1**. As expected, the spectrum of the carbon powder appears featureless. As carbon content in the sample increases, the overall albedo of the sample decreases and gypsum band depths

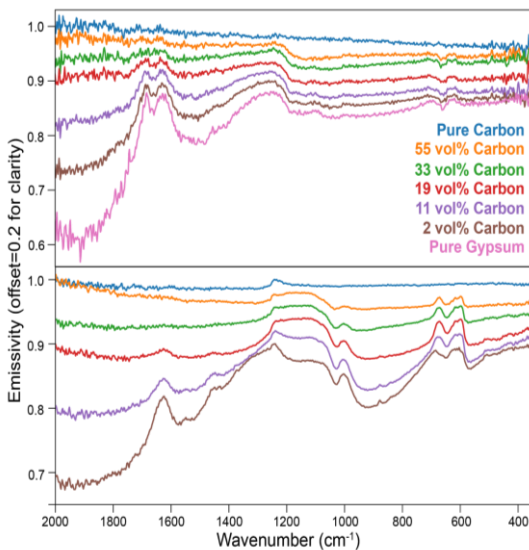
decrease. At carbon contents >33 vol%, many or all of the diagnostic gypsum bands are obscured.

Albedos of the gypsum/carbon mixtures are reported in **Table 1** and are derived from the VNIR reflectance spectra at 550 and 750 nm. Of these mixtures, the 55 volume% carbon-gypsum mixture matches the albedo of Bennu most closely. However, gypsum is a naturally bright mineral and therefore we anticipate that smaller amounts of carbon would be needed to darken other minerals to an equivalent albedo.

**Table 1.** Albedo of gypsum-carbon mixtures.

Weight% carbon	Volume% carbon	Reflectance at 550 nm	Reflectance at 750 nm
0	0	0.975	0.977
0.1	2	0.405	0.394
0.5	11	0.269	0.259
1	19	0.162	0.151
2	33	0.102	0.094
5	55	0.051	0.046

The TIR emission spectrum of pure carbon (**Figure 2**), similar to the VNIR data, is featureless. In both ambient and SAE conditions, as the proportion of gypsum increases within the mixtures, band depths increase and features broaden.



**Figure 2.** Ambient (top) and SAE (bottom) TIR emission spectra of gypsum with 0, 2, 11, 19, 33 and 55 volume% carbon.

**Discussion:** VNIR reflectance and TIR emission spectra of darkened gypsum mixtures show that when higher percentages of carbon powder are present, more gypsum-specific spectral features are obscured (Figures 1 and 2). Additionally, the more carbon within the sample, the lower the albedo of the sample will be. There is a tradeoff between lowering the albedo enough for the spectra to be analogous to Bennu while maintaining enough brightness that the majority of the VNIR and TIR spectral features are present. VNIR and TIR spectra have been collected for the 13 analog

minerals. These data will act as end-members within VNIR and TIR spectral libraries.

**Ongoing Work:** This work will be expanded over the next several months to include mineral mixtures composed of the 13 minerals studies here and which are analogs to CI and CM chondrites. The compositions of these 144 proposed fine-grained mixtures will match literature values [11-13] and will be darkened with carbon powder to lower the albedo of each mixture. The VNIR and TIR spectral libraries with CI and CM analog mineral mixtures will act as training sets available to the mission team. PLS multivariate analysis will be applied to these data sets for robust mineral abundance assessments of OTES and OVIRS spectra.

PLS is a common machine learning technique used for the prediction of chemical abundances [14, 15]. Traditional linear least squares models cannot be counted on to provide quantitative assessments of mineralogy for finely particulate materials. PLS is an alternative approach that removes the assumption of linear mixing across all wavelengths. This is useful given that at smaller grain sizes, TIR wavelengths (i.e., where the extinction coefficient  $k$  is low) can transmit through the grains and non-linear mixing effects occur.

While initial calculations of Bennu's thermal inertia suggest a coarsely particulate surface [16], additional data and modeling suggest a finely particulate regolith at equatorial latitudes [4, 17]. Upon the approach to the asteroid, boulders and coarse-grained materials have been observed extensively. However, during the detailed survey of Bennu, we may encounter patches of fine-grained material over small regions. Analysis of those regions (if they exist) are what would benefit most from this laboratory work and eventual PLS analyses.

**Acknowledgments:** This work was supported by the NASA OSIRIS-REx Participating Scientist program under a grant made to T. D. Glotch and A. D. Rogers. This material is based upon work supported by NASA under Contract NNM10AA11C issued through the New Frontiers Program.

**References:** [1] DeMeo, F. E. et al. (2009) *Icarus*, 202, 160-180. [2] Clark, B. E. et al. (2011) *Icarus*, 216, 462-475. [3] Hergenrother, C. W. et al. (2013) *Icarus*, 226(1), 663-670. [4] Binzel, R. P. et al. (2015) *Icarus*, 256, 22-29. [5] Clark, B. E. et al. (2010) *J. Geophys. Res.*, 115(E6). [6] Simon, A. A. et al. (2018) *Fall AGU Meeting*, abstract #P33C-3838. [7] Tucker, J. M. et al. (2010) *Chemical Geology*, 277, 137-148. [8] Dyar, M. D. et al. (2016) *Spectrochimica Acta B*, 123, 93-104. [9] Dyar, M. D. et al. (2016) *American Mineralogist*, 101, 1171-1189. [10] Breitenfeld, L. B. et al. (2018) *American Mineralogist*, 103, 1827-1836. [11] Bland, P. A. et al. (2004) *Meteoritics & Planetary Science*, 39(1), 3-16. [12] Howard, K. T. et al. (2011) *Geochim. Cosmochim. Ac.*, 75(10), 2735-2751. [13] King, A. J. et al. (2015) *Geochim. Cosmochim. Ac.*, 165, 148-160. [14] Dyar, M. D. et al. (2012) *Spectrochim. Acta B*, 70, 51-67. [15] Clegg, S. M. et al. (2009) *Spectrochim. Acta B*, 64(1), 79-88. [16] Emery, J. P. et al. (2014) *Icarus*, 234, 17-35. [17] Yu, L. and Ji, J. (2015) *MNRAS*, 452(1), 368-375.